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HYDRAULICS OF TWO-WAY COVERED RISERS

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PREFACE

This Technical Release presents the hydraulic behavior of the covered inlet of two-way covered risers as verified by both air and water model tests conducted by Messrs. F. W. Blaisdell, C. A. Donnelly, and C. G. Hebaus at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota. These tests were advocated by and conducted in consultation with Mr. M. M. Culp, Chief, Design Branch, Engineering Division, who conceived the covered inlet originally.

Various criteria and proportions of the two-way covered riser to be used for Standard Covered Risers were selected at a meeting of the "Subcommittee on Standard Structural Details" held in Spartanburg, South Carolina, during October 23 - 27, 1961. These proportions and criteria, together with other pertinent hydraulic and structural standards and criteria, are given in Engineering Standard Drawing ES-150, "Drop Inlet Spillways, Standard for Covered Top Riser," which was issued as one of the attachments to Engineering Memorandum SCS-50 dated May 16, 1963. This Technical Release is primarily concerned with the hydraulics of Standard Covered Risers. It also gives the desirable location and width of low stage inlets in two-way covered risers as shown by model studies.

Mr. Edwin S. Alling prepared this Technical Release under the supervision of Mr. Paul D. Doubt, Head, Design Unit, Design Branch, Engineering Division at Hyattsville, Maryland.

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NOMENCLATURE

a_b = area of the conduit

a_o = area of opening of low stage inlet

a_r = area of the riser

C_b = discharge coefficient for pipe flow

C_w = discharge coefficient for weir flow

C_o = discharge coefficient for orifice flow

D = pipe conduit diameter

fps = feet per second

H_h = head over crest of the covered inlet of the riser

H_ℓ = head over crest of the low stage inlet of the riser

H_o = pressure flow head, i.e., difference in elevation between the water surface in the reservoir and the point at which the hydraulic grade line intersects the plane of the conduit outlet. This point is usually taken as 0.5D above the invert of the conduit, or as the tailwater surface, whichever is the higher elevation.

h_a = atmospheric pressure head

h_{ab} = absolute pressure head

h_{fc} = head loss between the reservoir water surface and the mid-height of the riser

h_{ft} = head loss between the mid-height of the riser and the conduit entrance (including conduit entrance)

h_{pc} = pressure head on the crown of the conduit at a section $\frac{1}{2}$D downstream from the conduit entrance

h_{vb} = velocity head in the conduit

h_{vr} = velocity head in the riser

K_c = crest head loss coefficient

K_e = entrance head loss coefficient

K_p = friction head loss coefficient for circular pipe flowing full. Its value may be obtained from ES-42.

K_t = transition head loss coefficient

L = inside length of riser

L_b = length of the conduit

L_o = anti-vortex plate (cover slab) overhang, measured from the outside of the sidewall

N_{hc} = vertical opening of the covered inlet of the riser

N_{ih} = vertical distance from the pipe invert at the riser to the crest of the covered inlet of the riser

$N_{\ell u}$ = vertical opening of the low stage inlet of the riser

Q_{hc} = discharge through the covered inlet of the riser

$Q_{\ell u}$ = discharge through the low stage inlet of the riser

v_b = mean velocity of flow in the conduit

v_r = mean velocity of flow in the riser

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HYDRAULICS OF TWO-WAY COVERED RISERS

The two-way covered riser is considered to be the best drop inlet spillway riser for use under a wide variety of conditions.

Data on Two-way Covered Risers

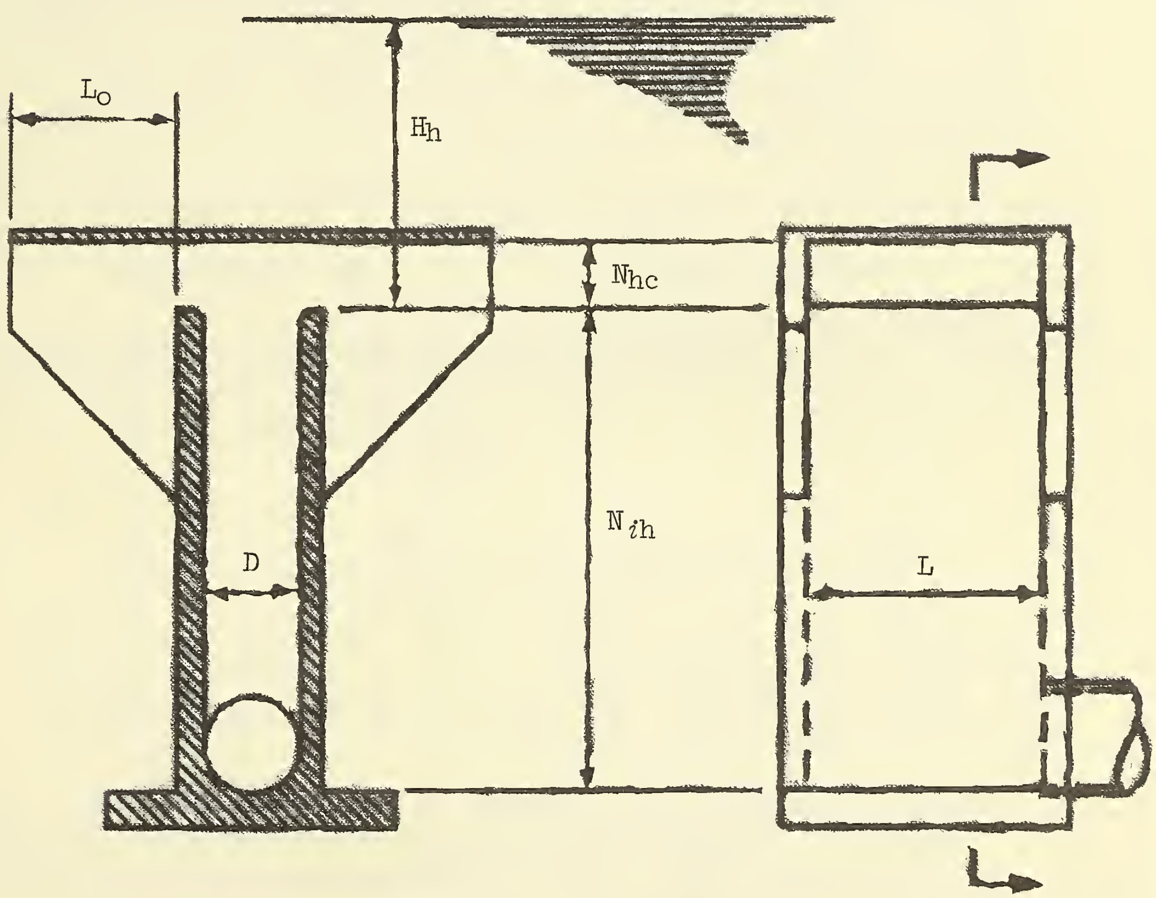

Figure 1. Definition sketch for two-way covered risers.

The vertical distances and other dimensions required to define the two-way covered riser, are illustrated by Figure 1 in which:

- D = pipe conduit diameter and inside width of riser
- H_h = head over crest of the covered inlet of the riser
- L = inside length of riser
- L_o = anti-vortex plate (cover slab) overhang, measured from the outside of the sidewall
- N_{hc} = vertical opening of the covered inlet of the riser
- N_{ih} = vertical distance from the pipe invert at the riser to the crest of the covered inlet of the riser
- Q_{hc} = discharge through the covered inlet of the riser

Limiting Values

Numerous model tests have been conducted to establish limiting values and to determine the hydraulic behavior of two-way covered risers. The range of values tested, or the limiting values are given below.

Length of riser, L:

$$1.0 \leqq L/D \leqq 10.0$$

Height of riser, N_{ih}:

$$N_{ih} \geqq 3D$$

Conduit slope:

slope ≦ 40 percent

Anti-vortex plate overhang, L_o:
Vortices, assuming suitable vertical openings N_{hc}, will not form if L_o is made $\geqq L_{o(min.)}$. Vortex formation may occur if L_o is made $< L_{o(min.)}$.

L/D	$L_{o(min.)}/D$
1.5	1.0
2.0	0.4
5.0	0.4
10.0	0.1

Vertical opening of inlet, N_{hc}:
The vertical opening, N_{hc}, may range between two limiting values, $N_{hc(max.)}$ and $N_{hc(min.)}$:

$N_{hc(max.)}$ is equal to the head at the intersection of the weir flow curve (extended) and the pipe flow curve as shown on Figure 2. If N_{hc} is made greater than this maximum value, vortex formation may not be prevented.

$N_{hc}(min.)$ is equal to the weir flow head at which $\frac{Q_{hc}}{D^{5/2}} = 5.1$ when $L/D \geqq 2$.

(This criterion is not valid for values $L/D < 2$, for example, if $L/D = 1.5$ the value of $N_{hc}(min.)$ is the head at which $\frac{Q_{hc}}{D^{5/2}} = 6.7$ to 7.4.)

If N_{hc} is made less than this minimum value, the conduit may not flow full.

Head-discharge Relations

The head-discharge relation may consist of portions of four curves as described below and as shown in Figure 2. The portions are:

(a) Weir flow for the range of heads from the crest of the covered inlet to the bottom of the anti-vortex plate.

$$Q_{hc} = C_w(2L)H_h^{3/2} = 3.1\ (2L)H_h^{3/2}$$

(b) A horizontal line, a constant-head curve, at a head equal to the vertical opening of the covered inlet, (N_{hc}), for the range of discharges from the weir flow curve to the curve (c) next defined or to (d) the pipe flow curve, whichever is first intersected by curve (b).

$$H_h/D = N_{hc}/D$$

(c) A straight line for the range of discharges from the horizontal line at the head equal to N_{hc} to an intersection with (d) the pipe flow curve. The equation of this line is:

$$\frac{H_h}{D} = \frac{N_{hc}}{D} - \left(\frac{0.2}{L/D} - 0.1\ \log_{10} \frac{L_o}{D}\right) + \left(0.1 - 0.05\ \frac{L_o}{D}\right) \frac{Q_{hc}}{(2L)D^{3/2}}$$

where

$\left(0.1 - 0.05\ \frac{L_o}{D}\right)$ is taken equal to zero

when $\frac{L_o}{D} \geqq 2$, and

$\left(\frac{0.2}{L/D} - 0.1\ \log_{10} \frac{L_o}{D}\right)$ is taken equal to zero

when $\frac{L_o}{D} \geqq (10)^{2/(L/D)}$

Thus the term,

$\left(\frac{0.2}{L/D} - 0.1\ \log_{10} \frac{L_o}{D}\right)$, is never taken less than zero.

(d) Pipe flow for heads and discharges larger than those defined in (b) and (c) above.

$$Q_{hc} = C_b a_b \sqrt{2gH_o}$$

where

C_b = a coefficient which depends on the characteristics of the riser and conduit

a_b = area of the conduit

H_o = pressure flow head, i.e., difference in elevation between the water surface in the reservoir and the point at which the hydraulic grade line intersects the plane of the conduit outlet. This point is usually taken as 0.5D above the invert of the conduit, or as the tailwater surface, whichever is the higher elevation.

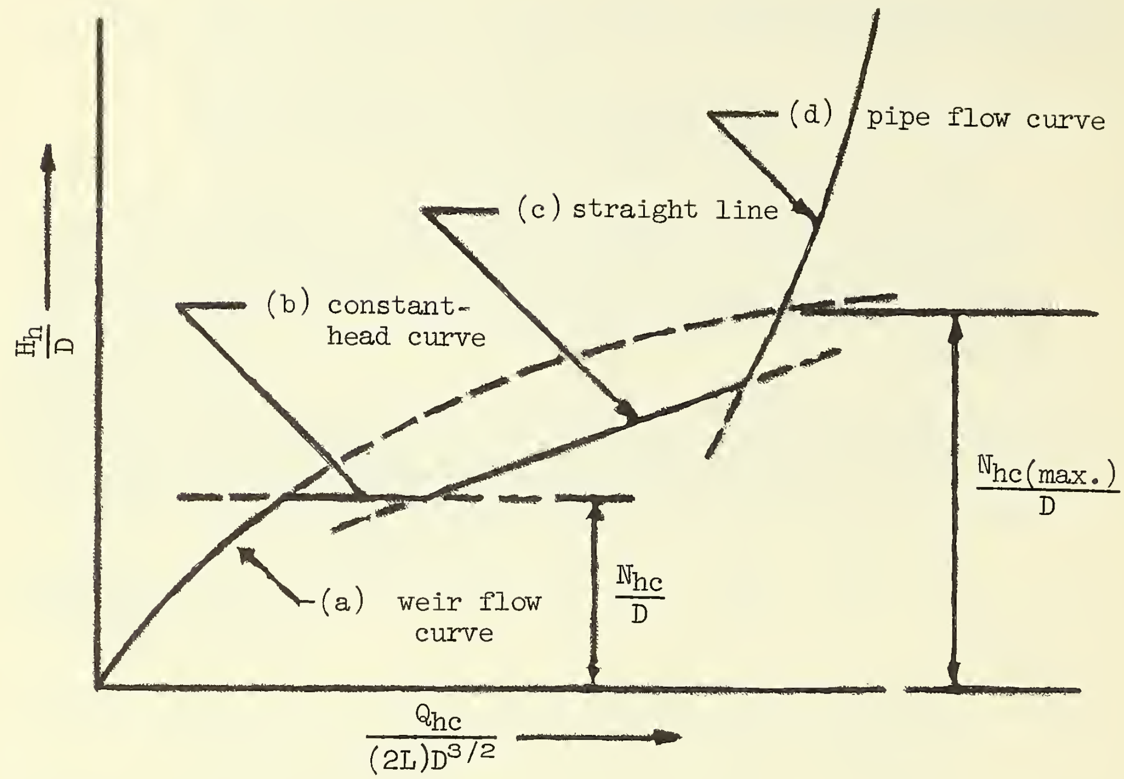

Figure 2. Head-discharge relation for two-way covered risers.

Note that the actual head-discharge relation, for specific riser proportions, may take one of several forms.

Example (1): If $L_o/D \geqq 2$, then curve (c) is horizontal and hence is not a part of the head-discharge relation.

Example (2): If H_o is sufficiently small, then the pipe flow curve (d) may intersect curve (b) to the left of curve (c) since curves (a), (b), and (c) are independent of H_o.

Example (3): If N_{hc} is made equal to its maximum value, then curves (b) and (c) are not a part of the head-discharge relation.

The Standard Covered Riser

Refer to Engineering Standard Drawing ES-150, "Drop Inlet Spillways, Standard for Covered Top Riser", and to Technical Release No. 30 "Structural Design of Standard Covered Risers". Hydraulic aspects and structural aspects of two-way covered risers were considered during the selection of the criteria and proportions establishing the Standard Covered Riser.

Proportions Selected

Length of riser, L:

$$L = 3D$$

Plate (cover slab) overhang, L_o:
Selected to provide adequate trash rack net area.

$$L_o = 2D$$

Vertical opening of inlet, N_{hc}:
Evaluating N_{hc} (max.)

The maximum allowable mean velocity in the pipe conduit of standard risers is set at $v_{b(max.)} = 30$ fps, thus

$$Q_{hc(max.)} = 30 \frac{\pi D^2}{4}$$

and, equating this to weir flow

$$30 \frac{\pi D^2}{4} = 3.1(6D)\ H_h^{3/2}$$

thus

$$H_h = N_{hc(max.)} = 1.17 D^{2/3}$$

or

$$\frac{N_{hc(max.)}}{D} = \frac{1.17}{D^{1/3}}$$

which gives

$$\frac{N_{hc(max.)}}{D} = \begin{cases} 0.93 \text{ for } D = 2.0 \text{ ft} \\ 0.74 \text{ for } D = 4.0 \text{ ft} \end{cases}$$

Evaluating $N_{hc(min.)}$

$L/D > 2$, thus

$$\frac{Q_{hc(min.)}}{D^{5/2}} = 5.1$$

and, equating this to weir flow

$$5.1D^{5/2} = 3.1(6D)\ H_h^{3/2}$$

thus

$$H_h = N_{hc(min.)} = 0.42D$$

or

$$\frac{N_{hc(min.)}}{D} = 0.42$$

N_{hc} selected

$$\frac{N_{hc}}{D} = 0.50$$

Head-discharge Relations

The term $(0.1 - 0.05 \frac{L_o}{D})$, in the equation of curve (c), equals zero since $\frac{L_o}{D} = 2$. Therefore curve (c) is horizontal and the head-discharge relation for Standard Covered Risers consists of portions of only three curves:

(a) weir flow curve
(b) constant-head curve
(d) pipe flow curve

as shown in Figure 3. The constant-head curve and the weir curve intersect at

$$\frac{H_h}{D} = \frac{N_{hc}}{D} = 0.5$$

and

$$Q'_{hc} = 3.1(6D)\ H_h^{3/2} = 3.1(6D)(0.50D)^{3/2} = 1.096(6)D^{5/2}$$

The location of the intersection of the constant-head curve and the pipe flow curve depends on the particular riser and conduit.

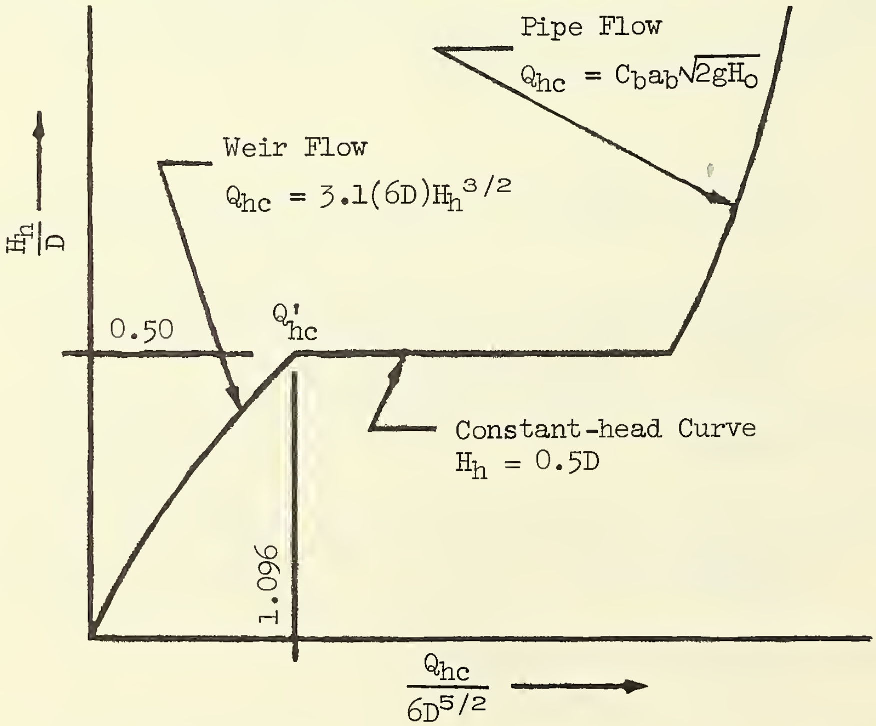

Figure 3. Head-discharge relation for Standard Covered Risers.

Thus as the reservoir water surface rises above the crest of the covered inlet of the Standard Covered Riser, the inlet functions as a weir for the range of heads from zero to 0.50D above the crest. The riser primes when the head over the crest of the covered inlet becomes equal to 0.50D and flow changes from weir control to pipe control.

Riser Head Losses

Head loss coefficients for pipe flow conditions are defined as follows:

$$K_c = \frac{h_{fc}}{h_{vr}} = \text{crest head loss coefficient}$$

$$K_t = \frac{h_{ft}}{h_{vb}} = \text{transition head loss coefficient}$$

$$K_e = \frac{h_{fc} + h_{ft}}{h_{vb}} = \text{entrance head loss coefficient}$$

where:

h_{fc} = head loss between the reservoir water surface and the mid-height of the riser

h_{ft} = head loss between the mid-height of the riser and the conduit entrance (including conduit entrance).

h_{vb} = the velocity head in the conduit

h_{vr} = the velocity head in the riser

From tests, for the Standard Covered Riser:

$K_c = 2.0$

$K_t = 0.55$

Since

$$a_r/a_b = 3D^2/\frac{\pi D^2}{4} = 3.82$$

then

$$v_r = v_b/3.82$$

and

$$h_{vr} = \frac{v_r^2}{2g} = \frac{1}{2g}\left(\frac{v_b}{3.82}\right)^2 = 0.0686\ \frac{v_b^2}{2g} = 0.0686\ h_{vb}$$

Thus

$$\begin{aligned} h_{fc} &= 2.0\ h_{vr} = 0.137\ h_{vb} \\ h_{ft} &= \phantom{2.0\ h_{vr} =}\ 0.55\ h_{vb} \\ \hline h_{fc} + h_{ft} &= 0.687\ h_{vb} = K_e h_{vb} \end{aligned}$$

For design, it has been recommended that $K_e = 1.0$ be used.

Pipe Flow, Energy and Hydraulic Grade Lines

The pipe flow equation for Standard Covered Risers may be derived from the relations shown in Figure 4. Thus, for full pipe flow:

$$H_o = \frac{v_b^2}{2g}(1 + K_e + K_pL_b) = \frac{v_b^2}{2g}(1 + 1 + K_pL_b)$$

or

$$v_b = \frac{1}{\sqrt{2 + K_pL_b}} \sqrt{2gH_o}$$

and

$$Q_{hc} = a_bv_b = \frac{1}{\sqrt{2 + K_pL_b}} a_b\sqrt{2gH_o} = C_ba_b\sqrt{2gH_o}$$

where

K_p = friction head loss coefficient for circular pipe flowing full. Its value may be obtained from ES-42.

L_b = length of the conduit

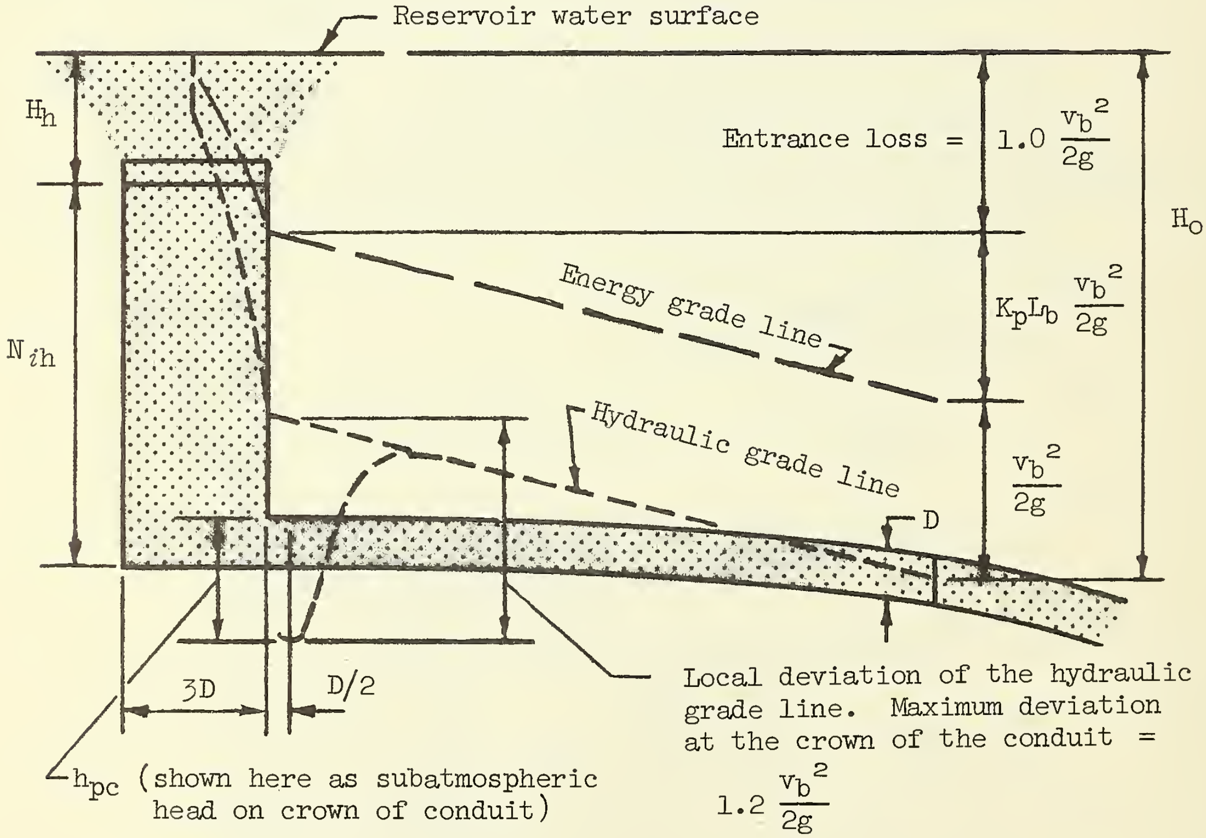

Figure 4. Pressure flow relations in Standard Covered Risers.

Contractions in the conduit near the entrance cause local deviations of the hydraulic grade line from its normally computed position. Tests show that the maximum deviation occurs at the crown of the conduit at a distance of about D/2 downstream from the conduit entrance. As indicated by Figure 4, negative pressures (below atmospheric) are possible in this region. From the figure, the pressure head on the crown of the conduit (h_{pc}) at a distance of D/2 from the riser may be written as:

$$h_{pc} = (H_h + N_{ih}) - (1 + K_e + 1.2) \frac{v_b^2}{2g} - D$$

or, with $K_e = 1.0$

$$h_{pc} = (H_h + N_{ih} - D) - 3.2 \frac{v_b^2}{2g} = (H_h + N_{ih} - D) - 3.2 \frac{H_o}{2 + K_p L_b}$$

Upon substitution of values, a positive result means the absolute pressure is greater than atmospheric, a negative result means the absolute pressure is less than atmospheric.

To avoid cavitation, the absolute pressure must be greater than the vapor pressure corresponding to the temperature of the water. The absolute pressure head at the crown of the conduit at D/2 downstream from the conduit entrance is given algebraically by:

$$h_{ab} = h_a + h_{pc}$$

where h_a is the atmospheric pressure head.

Low Stage Inlets

It was originally believed that low stage inlets should be located in the riser endwalls and the width should equal the clear width of the endwall. Subsequently, model tests showed such inlets had a detrimental effect on the hydraulic behavior of two-way covered risers.

Tests with openings in the sidewalls and tests with openings in the endwalls showed low stage inlets should be located in the endwalls and the width should equal (3/4)D and be centered in the wall.

As the reservoir water surface rises above the elevation of the crest of the low stage inlet, the inlet first functions as a weir, then with increasing water level, the inlet functions as an orifice. Weir flow is given by:

$$Q_{\ell u} = 3.1(\tfrac{3}{4}D)\ H_{\ell}^{3/2}$$

where

H_{ℓ} = head over crest of the low stage inlet of the riser.

$Q_{\ell u}$ = discharge through the low stage inlet of the riser

Orifice flow is given by:

$$Q_{\ell u} = C_o a_o \sqrt{2g(H_{\ell} - \tfrac{1}{2} N_{\ell u})} = 0.60 \left(\tfrac{3}{4}D\ N_{\ell u} \right) \sqrt{2g(H_{\ell} - \tfrac{1}{2} N_{\ell u})}$$

where

$N_{\ell u}$ = vertical opening of the low stage inlet of the riser.